Micropower, Zero Drift, True Rail-to-Rail Instrumentation Amplifier

Preliminary Technical Data

AD8237

FEATURES

- Gain set with 2 external resistors
  - Can achieve low gain drift at all gains
- Ideal for portable systems
  - Maximum supply current: 130 µA
  - Rail-to-rail input and output
  - Zero input crossover distortion
- Designed for excellent dc performance
  - Minimum CMRR: 110 dB
  - Maximum offset voltage drift: 0.2 µV/°C
  - Maximum gain error: 0.005% (all gains)
  - Maximum gain drift: 0.5 ppm/°C (all gains)
- Single-supply operation: 1.8 V to 5.5 V
- 8-lead MSOP package

APPLICATIONS

- Bridge amplification
- Pressure measurement
- Medical instrumentation
- Portable systems
- Current measurement

GENERAL DESCRIPTION

The AD8237 is a micropower, zero drift, rail-to-rail input and output instrumentation amplifier. The relative match of two resistors sets any gain from 1 to 1000. The AD8237 has excellent gain accuracy performance that can be preserved at any gain with two ratio-matched resistors.

The AD8237 uses a novel indirect current-feedback architecture to achieve a true rail-to-rail capability. Unlike conventional in-amps, the AD8237 can fully amplify signals with common-mode voltage at or even slightly beyond its supplies. This enables applications with high common-mode voltages to use smaller supplies and save power.

The AD8237 is an excellent choice for portable systems. With a minimum supply voltage of 1.8 V, a 115 µA typical supply current, and wide input range, the AD8237 makes full use of a limited power budget, while still offering bandwidth and drift performance suitable for bench-top systems.

The AD8237 is available in an 8-lead MSOP package. Performance is specified over the full temperature range of −40°C to +125°C.

PIN CONFIGURATION

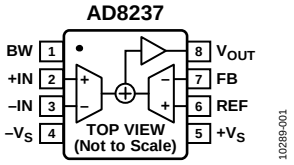


Figure 1.

Table 1. Instrumentation Amplifiers by Category[1]

General Purpose	Zero Drift	Military Grade	Micropower	Digital Gain
AD8421	AD8237	AD620	AD8237	AD8250
AD8221/AD8222	AD8231	AD621	AD8420	AD8251
AD8220/AD8224	AD8293	AD524	AD8235/AD8236	AD8253
AD8228	AD8553	AD526	AD627	AD8231
AD8295	AD8556	AD624		
AD8226	AD8557			

[1] See www.analog.com for the latest instrumentation amplifiers.

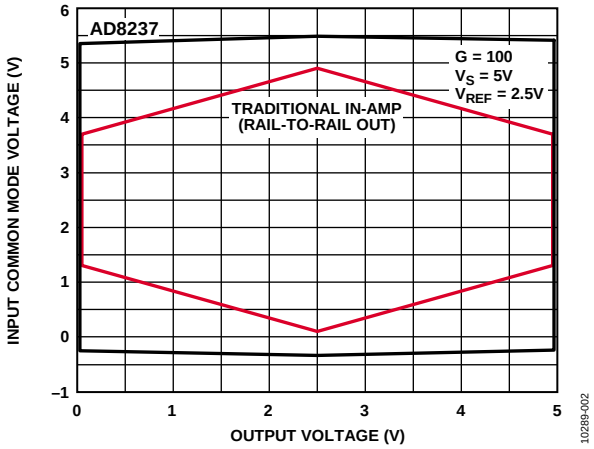


Figure 2. Input Common-Mode Voltage vs. Output Voltage, +V_S = 5 V, G = 100

Rev. PrA

Information furnished by Analog Devices is believed to be accurate and reliable. However, no responsibility is assumed by Analog Devices for its use, nor for any infringements of patents or other rights of third parties that may result from its use. Specifications subject to change without notice. No license is granted by implication or otherwise under any patent or patent rights of Analog Devices. Trademarks and registered trademarks are the property of their respective owners.

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781.329.4700 www.analog.com
Fax: 781.461.3113
©2012 Analog Devices, Inc. All rights reserved.

TABLE OF CONTENTS

Features ... 1
Applications ... 1
General Description ... 1
Pin Configuration ... 1
Specifications ... 3
Absolute Maximum Ratings ... 7
Thermal Resistance ... 7
ESD Caution ... 7
Pin Configuration and Function Descriptions ... 8
Theory of Operation ... 9
Architecture ... 9
Setting the Gain ... 9
Gain Accuracy ... 10
Clock Feedthrough ... 10
Input Voltage Range ... 10
Input Protection ... 10
Filtering Radio Frequency Interference ... 11
Using the Reference Pin ... 11
Layout ... 11
Input Bias Current Return Path ... 12
Outline Dimensions ... 13

SPECIFICATIONS

$+V_S$ = +5 V, $-V_S$ = 0 V, V_{REF} = 2.5 V, V_{CM} = 2.5 V, T_A = 25°C, G = 1 to 1000, R_L = 10 kΩ to ground, specifications referred to input, unless otherwise noted.

Table 2.

Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
COMMON-MODE REJECTION RATIO (CMRR)	V_{CM} = 0.2 V to 4.8 V				
CMRR DC to 60 Hz					
G = 1, G = 10		110	120		dB
G = 100, G = 1000		120	140		dB
Over Temperature (G = 1)	T_A = −40°C to +125°C	106			dB
CMRR at 1 kHz		80			dB
NOISE					
Voltage Noise					
Spectral Density	f = 1 kHz		70		nV/√Hz
Peak to Peak	f = 0.1 Hz to 10 Hz		1.5		µV p-p
Current Noise					
Spectral Density	f = 1 kHz		100		fA/√Hz
Peak to Peak	f = 0.1 Hz to 10 Hz		TBD		pA p-p
VOLTAGE OFFSET					
Offset				60	µV
Average Temperature Coefficient	T_A = −40°C to +125°C			0.2	µV/°C
Offset RTI vs. Supply (PSR)		106			dB
INPUTS[1]	Valid for REF and FB pair, as well as +IN and −IN				
Input Bias Current	T_A = +25°C			0.5	nA
	T_A = −40°C to +85°C			1	nA
	T_A = +125°C			15	nA
Input Offset Current	T_A = +25°C			0.5	nA
	T_A = −40°C to +85°C			1	nA
	T_A = +125°C			5	nA
Input Impedance					
Differential			200||5		MΩ||pF
Common Mode			600||10		MΩ||pF
Differential Input Operating Voltage	T_A = −40°C to +125°C	−3.8		3.8	V
Input Operating Voltage (+IN, −IN, or REF)	T_A = +25°C	$-V_S$ − 0.3		$+V_S$ + 0.3	V
	T_A = −40°C to +125°C	$-V_S$ − 0.2		$+V_S$ + 0.2	V
DYNAMIC RESPONSE					
Small Signal Bandwidth	−3 dB				
Low Bandwidth Mode	Pin 1 connected to $-V_S$				
G = 1			200		kHz
G = 10			20		kHz
G = 100			2		kHz
G = 1000			0.2		kHz
High Bandwidth Mode	Pin 1 connected to $+V_S$				
G = 10			100		kHz
G = 100			10		kHz
G = 1000			1		kHz

Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
Settling Time 0.01%	4 V output step				
Low Bandwidth Mode	Pin 1 connected to $-V_S$				
G = 1			80		µs
G = 10			100		µs
G = 100			440		µs
G = 1000			4		ms
High Bandwidth Mode	Pin 1 connected to $+V_S$				
G = 10			80		µs
G = 100			100		µs
G = 1000			820		µs
Slew Rate					
Low Bandwidth Mode			0.05		V/µs
High Bandwidth Mode			0.15		V/µs
EMI Filter Frequency			6		MHz
GAIN[2]	G = 1 + (R2/R1)				
Gain Range[3]		1		1000	V/V
Gain Error	V_{OUT} = 0.2 V to 3.3 V, G = 1 to G = 1000			0.005	%
Gain Error vs. V_{CM}				TBD	ppm
Gain vs. Temperature	T_A = −40°C to +125°C			0.5	ppm/°C
Gain Nonlinearity	V_{OUT} = 0.2 V to 4.8 V, R_L = 10 kΩ to ground				
G = 1, G = 10			3		ppm
G = 100			6		ppm
G = 1000			10		ppm
OUTPUT					
Output Swing					
R_L = 10 kΩ to midsupply					
	T_A = +25°C	$-V_S$ + 0.05		$+V_S$ − 0.05	V
	T_A = −40°C to 125°C	$-V_S$ + 0.07		$+V_S$ − 0.07	V
R_L = 100 kΩ to midsupply					
	T_A = +25°C	$-V_S$ + 0.02		$+V_S$ − 0.02	V
	T_A = −40°C to 125°C	$-V_S$ + 0.03		$+V_S$ − 0.03	V
Short-Circuit Current			4		mA
POWER SUPPLY					
Operating Range		1.8		5.5	V
Quiescent Current	T_A = +25°C		115	130	µA
	T_A = −40°C to +125°C			150	µA
TEMPERATURE RANGE					
Specified		−40		+125	°C

[1] Specifications apply to input voltages between 0 V and 5 V. When measuring voltages beyond the supplies, there is additional offset error, bias currents increase and input impedance decrease, especially at higher temperatures.
[2] For G > 1, errors from the external resistors, R1 and R2, must be added to these specifications, including error from the FB pin bias current.
[3] The AD8237 has only been characterized for gains of 1 to 1000; however, higher gains are possible.

$+V_S$ = 1.8 V, $-V_S$ = 0 V, V_{REF} = 0.9 V, V_{CM} = 0.9 V, T_A = 25°C, G = 1 to 1000, R_L = 10 kΩ to ground, specifications referred to input, unless otherwise noted.

Table 3.

Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
COMMON-MODE REJECTION RATIO (CMRR)	V_{CM} = 0.2 V to 1.6 V				
CMRR DC to 60 Hz					
G = 1, G = 10		106	120		dB
G = 100, G = 1000		120	140		dB
Over Temperature (G = 1)	T_A = −40°C to +125°C	104			dB
CMRR at 1 kHz		80			dB
NOISE					
Voltage Noise					
Spectral Density	f = 1 kHz, V_{DIFF} ≤ 100 mV		70		nV/√Hz
Peak to Peak	f = 0.1 Hz to 10 Hz, V_{DIFF} ≤ 100 mV		1.5		µV p-p
Current Noise					
Spectral Density	f = 1 kHz		100		fA/√Hz
Peak to Peak	f = 0.1 Hz to 10 Hz		TBD		pA p-p
VOLTAGE OFFSET					
Offset				60	µV
Average Temperature Coefficient	T_A = −40°C to +125°C			0.2	µV/°C
Offset RTI vs. Supply (PSR)		106			dB
INPUTS[1]	Valid for REF and FB pair, as well as +IN and −IN				
Input Bias Current	T_A = +25°C			0.5	nA
	T_A = −40°C to +85°C			1	nA
	T_A = +125°C			15	nA
Input Offset Current	T_A = +25°C			0.5	nA
	T_A =−40°C to +85°C			1	nA
	T_A = −125°C			5	nA
Input Impedance					
Differential			200||5		MΩ||pF
Common Mode			600||10		MΩ||pF
Differential Input Operating Voltage	T_A = −40°C to +125°C	−0.7		+0.7	V
Input Operating Voltage (+IN, −IN, REF, or FB)	T_A = +25°C	$-V_S$ − 0.3		$+V_S$ + 0.3	V
	T_A = −40°C to +125°C	$-V_S$ − 0.2		$+V_S$ + 0.2	V
DYNAMIC RESPONSE					
Small Signal Bandwidth	−3 dB				
Low Bandwidth Mode	Pin 1 connected to $-V_S$				
G = 1			200		kHz
G = 10			20		kHz
G = 100			2		kHz
G = 1000			0.2		kHz
High Bandwidth Mode	Pin 1 connected to $+V_S$				
G = 10			100		kHz
G = 100			10		kHz
G = 1000			1		kHz
Slew Rate					
Low Bandwidth Mode			0.05		V/µs
High Bandwidth Mode			0.15		V/µs
EMI Filter Frequency			6		MHz

Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
GAIN[2]	G = 1 + (R2/R1)				
Gain Range[3]		1		1000	V/V
Gain Error	V_{OUT} = 0.2 V to 1.0 V, G = 1 to G = 1000			0.005	%
Gain Error vs. V_{CM}				TBD	ppm
Gain vs. Temperature	T_A = −40°C to +125°C			0.5	ppm/°C
Gain Nonlinearity	V_{OUT} = 0.2 V to 1.6 V				
G = 1, G = 10			3		ppm
G = 100			6		ppm
G = 1000			10		ppm
OUTPUT					
Output Swing					
R_L = 10 kΩ to midsupply					
	T_A = +25°C	$-V_S$ + 0.05		$+V_S$ − 0.05	V
	T_A = −40°C to 125°C	$-V_S$ + 0.07		$+V_S$ − 0.07	V
R_L = 100 kΩ to midsupply					
	T_A = +25°C	$-V_S$ + 0.02		$+V_S$ − 0.02	V
	T_A = −40°C to 125°C	$-V_S$ + 0.03		$+V_S$ − 0.03	V
Short-Circuit Current			4		mA
POWER SUPPLY					
Operating Range		1.8		5.5	V
Quiescent Current	T_A = +25°C		115	130	µA
	T_A = −40°C to +125°C			150	µA
TEMPERATURE RANGE					
Specified		−40		+125	°C

[1] Specifications apply to input voltages between 0 V and 1.8 V. When measuring voltages beyond the supplies, there is additional offset error, bias currents increase, and input impedance decrease, especially at higher temperatures.
[2] For G > 1, errors from the external resistors, R1 and R2, must be added to these specifications, including error from the FB pin bias current.
[3] The AD8237 has only been characterized for gains of 1 to 1000; however, higher gains are possible.

ABSOLUTE MAXIMUM RATINGS

Table 4.

Parameter	Rating
Supply Voltage	6 V
Output Short-Circuit Current Duration	Indefinite
Maximum Voltage at −IN, +IN, FB, or REF[1]	$+V_S$ + 0.3 V
Minimum Voltage at −IN, +IN, FB, or REF[1]	$-V_S$ − 0.3 V
Storage Temperature Range	−65°C to +150°C
Junction Temperature Range	−65°C to +150°C
ESD	
Human Body Model	8 kV
Charge Device Model	1.25 kV
Machine Model	0.2 kV

[1] If input voltages beyond the specified minimum or maximum voltages are expected, place resistors in series with the inputs to limit the current to 5 mA.

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

THERMAL RESISTANCE

θ_{JA} is specified for a device in free air.

Table 5.

Package	θ_{JA}	Unit
8-Lead MSOP, 4-Layer JEDEC Board	135	°C/W

ESD CAUTION

ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

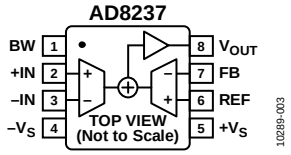


Figure 3. Pin Configuration

Table 6. Pin Function Descriptions

Pin No.	Mnemonic	Description
1	BW	Connect this pin to $+V_S$ for high bandwidth mode, and connect this pin to $-V_S$ for low bandwidth mode.
2	+IN	Positive Input.
3	−IN	Negative Input.
4	$-V_S$	Negative Supply.
5	$+V_S$	Positive Supply.
6	REF	Reference Input.
7	FB	Feedback Input.
8	V_{OUT}	Output.

THEORY OF OPERATION

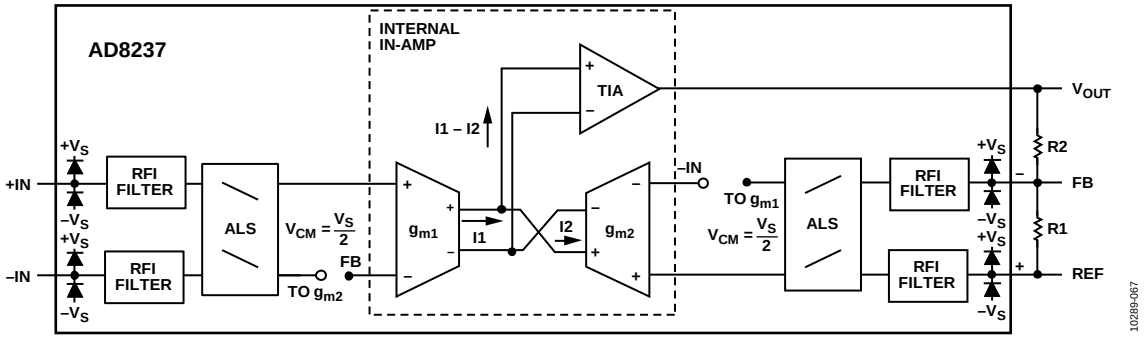


Figure 4. Simplified Schematic

ARCHITECTURE

The AD8237 is based on an indirect current feedback topology consisting of three amplifiers: two matched transconductance amplifiers that convert voltage to current, and one transimpedance amplifier that converts current to voltage.

To understand how the AD8237 works, first consider only the internal in-amp. Assume a positive differential voltage is applied across the inputs of the transconductance amplifier, g_m1. This input voltage is converted into a differential current, I1, by the g_m. Initially, I2 is zero; therefore, I1 is fed into the TIA, causing the output to increase. If there is feedback from the output of the TIA to the negative terminal of g_m2, and the positive terminal is held constant, the increasing output of the TIA causes I2, as shown, to increase. When it is assumed that the TIA has infinite gain, the loop is satisfied when I2 equals I1. Because the gain of g_m1 and g_m2 are matched, this means that the differential input voltage across g_m1 appears across the inputs of g_m2. This behavioral model is all that is needed for proper operation of the AD8237, and the rest of the circuit is for optimization of performance.

The AD8237 employs a novel adaptive level shift (ALS) technique. This is a switched capacitor method that shifts the common-mode level of the input signal to the optimal level for the in-amp while preserving the differential signal. Once this is accomplished, additional performance benefits can be achieved by using the internal in-amp to compare +IN to FB and –IN to REF. This is only practical because the signals coming out of the ALS blocks are all referred to the same common-mode potential.

In traditional instrumentation amplifiers, the input common-mode voltage can limit the available output swing, typically depicted in a hexagon plot. Because of this limit, there are very few instrumentation amplifiers that can measure small signals near either supply rail. The AD8237 employs the indirect current feedback topology and ALS to achieve a truly rail-to-rail characteristic.

The AD8237 includes an RFI filter to remove high frequency out-of-band signals without affecting input impedance and CMRR over frequency. Additionally, there is a bandwidth mode pin to adjust the compensation. For gains greater than or equal to 10, the mode pin (BW) can be tied to $+V_S$ to change the compensation and increase the gain bandwidth product of the amplifier to 1 MHz. Otherwise, connect the mode pin to $-V_S$ for a 200 kHz gain bandwidth product.

SETTING THE GAIN

There are several ways to configure the AD8237. The transfer function of the AD8237 in the configuration in Figure 4 is

$$V_{OUT} = G(V_{IN+} - V_{IN-}) + V_{REF}$$

where:

$$G = 1 + \frac{R2}{R1}$$

Table 7. Suggested Resistors for Various Gains (1% Resistors)

R1 (kΩ)	R2 (kΩ)	Gain
None	Short	1.00
49.9	49.9	2.00
20	80.6	5.03
10	90.9	10.09
5	95.3	20.06
2	97.6	49.8
1	100	101
1	200	201
1	499	500
1	1000	1001

While the ratio of R2 to R1 sets the gain, the designer determines the absolute value of the resistors. Larger values reduce power consumption and output loading; smaller values limit the FB input bias current and offset current error. If the parallel combination of R1 and R2 is greater than about 30 kΩ, the resistors start to contribute to the noise. For best output swing and linearity, keep $(R1 + R2) \parallel R_L \geq 10$ kΩ.

FB bias current error can be reduced by placing a resistor of value R1||R2 in series with the REF terminal, as shown in Figure 5. At higher gains, this resistor can simply be the same value as R1.

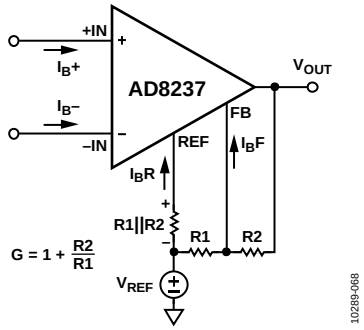


Figure 5. Cancelling Error from FB Input Bias Current

Some applications may be able to take advantage of the symmetry of the input transconductance amplifiers by canceling input impedance errors, as shown in Figure 6. If the source resistance is well known, setting the parallel combination of R1 and R2 equal to R_S accomplishes this. Pay careful attention to output loading and noise to determine if this is practical.

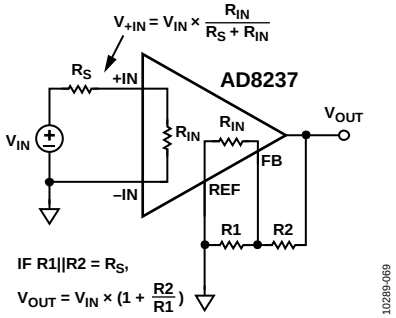


Figure 6. Canceling Input Impedance Errors

GAIN ACCURACY

Unlike most instrumentation amplifiers, the relative match of the two gain setting resistors determines the gain accuracy of the AD8237 rather than a single external resistor. For example, if two resistors have exactly the same absolute error, there is no error in gain. Conversely, two 1% resistors can cause approximately 2% maximum gain error at high gains. Temperature coefficient mismatch of the gain setting resistors increases the gain drift of the instrumentation amplifier circuit according to the gain equation. Because these external resistors do not have to match any on-chip resistors, resistors with good TC tracking can achieve excellent gain drift.

CLOCK FEEDTHROUGH

The AD8237 uses nonoverlapping clocks to perform the chopping and ALS functions. The input voltage-to-current amplifiers are chopped at approximately 27 kHz.

Although there is internal ripple-suppression circuitry, trace amounts of these clock frequencies and their harmonics can be observed at the output in some configurations. These ripples are typically 100 µV RTI when the bandwidth is greater than the clock frequency. They can be larger after a transient but settle back to nominal, which is included in the settling time specifications. The amount of feedthrough at the output is dependent upon the gain and bandwidth mode. The worst case is in high bandwidth mode when the gain can be almost 40 before the clock ripple is outside the bandwidth of the amplifier. For some applications, it may be necessary to use additional filtering after the AD8237 to remove this ripple.

INPUT VOLTAGE RANGE

The allowable input range of the AD8237 is much simpler than traditional architectures. For the transfer function of the AD8237 to be valid, the input voltage must follow two rules

- Keep the differential input voltage within ±(Total Supply Voltage – 1.2) V.
- Keep the voltage of the inputs (including the REF and FB pins) and the output within the specified voltage range, which are approximately the supply rails.

Because the output swing is completely independent of the input common-mode voltage, there are no hexagonal figures or complicated formulas to follow, and no limitation for the output swing the amplifier has for input signals with changing common mode.

INPUT PROTECTION

If no external protection is used, keep the inputs of the AD8237 within the voltages specified in the absolute maximum ratings. If the application requires voltages beyond these ratings, input protection resistors can be placed in series with the inputs of the AD8237 to limit the current to 5 mA. For example, if $+V_S$ is 3 V and a 10 V overload voltage can occur at the inputs, place a protection resistor of at least (10 V – 3 V)/5 mA = 1.4 kΩ in series with inputs.

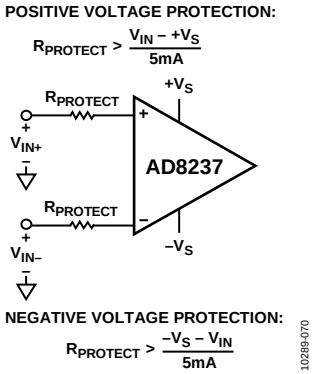


Figure 7. Protection Resistors for Large Input Voltages

FILTERING RADIO FREQUENCY INTERFERENCE

The AD8237 contains an on-chip RFI filter that is sufficient for a majority of applications. For applications where additional radio frequency immunity is needed, an external RFI filter can also be applied as shown in Figure 8.

$$\text{DIFFERENTIAL FILTER CUTOFF} = \frac{1}{2\pi R (2C_D + C_C)}$$

$$\text{COMMON-MODE FILTER CUTOFF} = \frac{1}{2\pi R C_C}$$

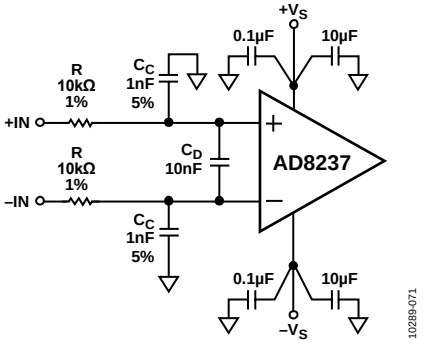
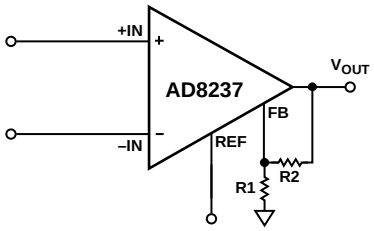


Figure 8. Adding Extra RFI Filtering

USING THE REFERENCE PIN

In general, instrumentation amplifier reference pins can be useful for a few reasons. They provide a means of physically separating the input and output grounds to reject ground bounce common to the inputs. They can also be used to precisely level-shift the output signal. In the configuration shown in Figure 4 through Figure 6, the gain of the reference pin to the output is unity, as is common in a typical in-amp. Because the reference pin is functionally no different from the positive input, it can be used with gain, as shown in Figure 9. This can be very useful in certain cases, such as dc-removal servo loops, which typically use inverting integrators. This requires special attention to the input range (especially at REF) and the output range. All three input voltages are referred to the one ground shown, which may need to be a low impedance midsupply.



$$V_{OUT} = (V_{REF} + V_{+IN} - V_{-IN})\left(1 + \frac{R2}{R1}\right)$$

Figure 9. Applying Gain to the Reference Voltage

Traditional instrumentation amplifier architectures require the reference pin to be driven with a low impedance source. In these traditional architectures, impedance at the reference pin degrades both CMRR and gain accuracy. With the AD8237 architecture, resistance at the reference pin has no effect on CMRR.

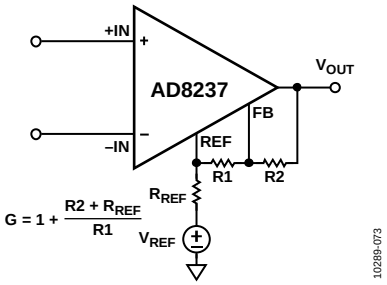


Figure 10. Calculating Gain with Reference Resistance

Resistance at the reference pin does affect the gain of the AD8237; however, if this resistance is constant, the gain setting resistors can be adjusted to compensate. For example, the AD8237 can be driven with a voltage divider, as shown in Figure 11.

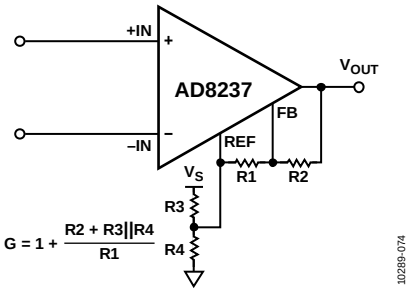


Figure 11. Using Resistor Divider to Set Reference Voltage

LAYOUT

Common-Mode Rejection Ratio over Frequency

Poor layout can cause some of the common-mode signal to be converted to a differential signal before reaching the in-amp. This conversion can occur when the path to the positive input pin has a different frequency response than the path to the negative input pin. For best CMRR vs. frequency performance, closely match the impedance of each path. Place additional source resistance in the input path (for example, for input protection) close to the in-amp inputs to minimize their interaction with the parasitic capacitance from the printed circuit board (PCB) traces.

Power Supplies

Use a stable dc voltage to power the instrumentation amplifier. Noise on the supply pins can adversely affect performance.

Place a 0.1 µF capacitor as close as possible to each supply pin. As shown in Figure 12, a 10 µF tantalum capacitor can be used farther away from the part. This capacitor, which is intended to be effective at low frequencies, can usually be shared by other precision integrated circuits. Keep the traces between these integrated circuits short to minimize interaction of the trace parasitic inductance with the shared capacitor. If a single supply is used, decoupling capacitors at $-V_S$ can be omitted.

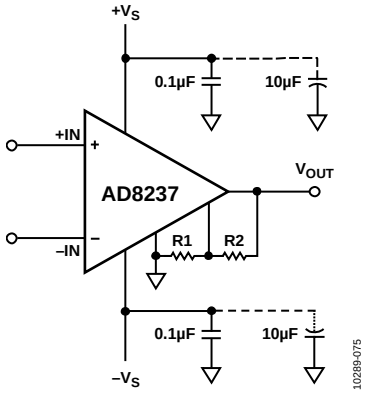


Figure 12. Supply Decoupling, REF, and Output Referred to Local Ground

Reference

The output voltage of the AD8237 is developed with respect to the potential on the reference terminal. Take care to tie REF to the appropriate local ground.

INPUT BIAS CURRENT RETURN PATH

The input bias current of the AD8237 must have a return path to ground. When the source, such as a thermocouple, cannot provide a return current path, create one, as shown in Figure 13.

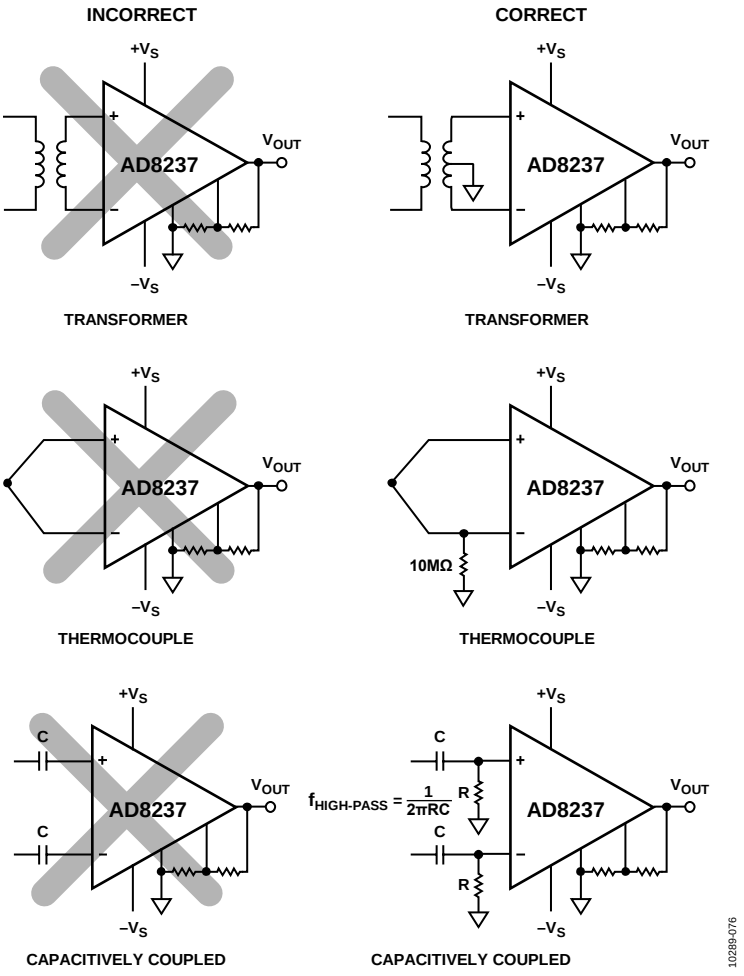
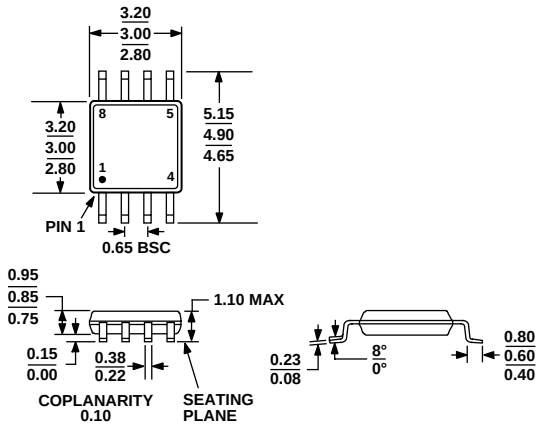


Figure 13. Creating an I_{BIAS} Path

OUTLINE DIMENSIONS



COMPLIANT TO JEDEC STANDARDS MO-187-AA

Figure 14. 8-Lead Mini Small Outline Package [MSOP]
(RM-8)
Dimensions shown in millimeters

©2012 Analog Devices, Inc. All rights reserved. Trademarks and registered trademarks are the property of their respective owners.
PR10289-0-6/12(PrA)